Continuous Broadband Monitoring of Crustal Deformation Near Active Faults in Southern California

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This grant helps to support the operation of two facilities for the continuous measurement of strain changes in southern California: Piñon Flat Observatory (PFO), between the San Jacinto and San Andreas faults, and at Durmid Hill (DHL), near the southern end of the San Andreas fault—and effectively within the fault zone. Other operational support for PFO is provided by SCEC, and matching funds from SIO; the latter also helps support operations at DHL.

The instruments at these locations (a single longbase strainmeter at DHL, three strainmeters and two tiltmeters at PFO) measure crustal deformation in Southern California for periods from seconds to years. By recording strain over this wide range of frequencies these measurements provide a nearly unique bridge between seismology and geodesy that is rarely available. At PFO, intercomparison of results from many types of sensors gives the best instruments available An accurate record of strain and tilt changes in the area near the observatories provides a better understanding of the mechanics of faulting, used both for studies of the seismic cycle in Southern California and for comparison with other types of measurements of crustal deformation.

This award provides funding primarily for operation of the observatories including support for power distribution, data recording, preliminary data-processing, and data distribution: all fairly basic activities, but all needed if the observatory is to operate. Part of the support is to cover the creation of well-edited versions of the data, under the supervision of the PIs. (It remains the case that considerable skilled post-processing of the data is required to produce high-quality results.)

In the absence of a significant geophysical event, it is in the nature of this kind of data collection that there may not be something new to report in the data every year; however, even

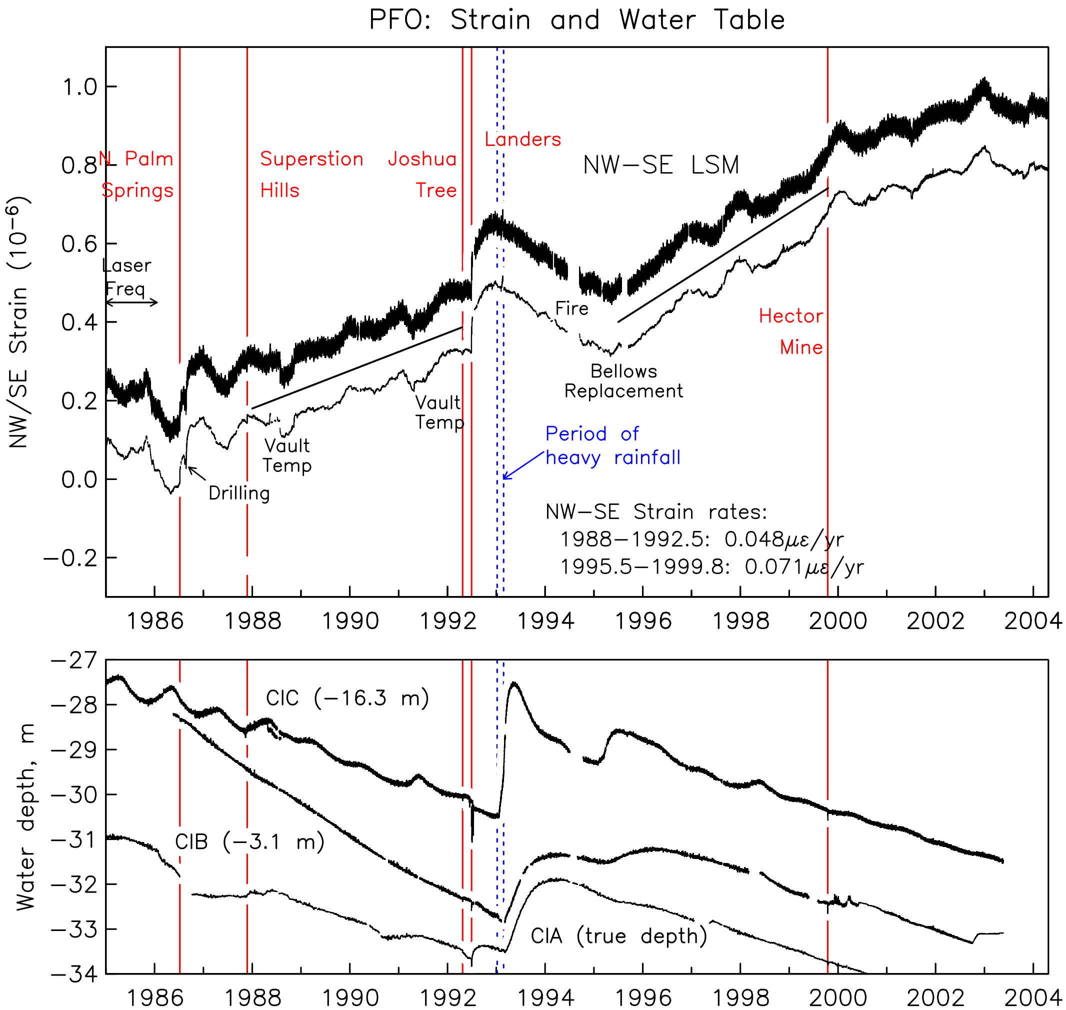

Figure 1

without events, the accumulation of data can reveal new information. **Figure 1** shows a possible example in the best and longest record we have, from the NW-SE laser strainmeter. As this figure shows, we recorded a large, several-year postseismic response to the Landers earthquake in 1992.5; this ended in early 1995. We have also recorded significant signals from the 16 October 1999 Hector Mine earthquake, though the postseismic strains from Hector Mine are much smaller. These data show that the multi-year strain rate seen on this instrument was significantly higher between these two earthquakes than for the period before or after them: a particular observation not available from other systems, and one that (obviously) could be made only with continuing long-term support.

For DHL we show (**Figure 2**) the records from the only fully-anchored strainmeter (NS), which shows a secular trend of –0.31 $\mu\varepsilon$/yr. Fitting a spatially uniform strain to velocities of geodetic stations nearby gives a rate of –0.41±0.09 $\mu\varepsilon$/yr; a dislocation model of the San Andreas fault and Brawley Seismic Zone, with a deep slip rate at 25 mm/yr and a locking depth of 11 km, gives –0.27 $\mu\varepsilon$/yr. We conclude that the strainmeter is recording the secular strain correctly, even in the poorly consolidated material around Durmid Hill. Parts of the strain record show an annual cycle, with an amplitude of 35 nε, and a phase of 37° relative to January 1. (The local air temperature has an annual cycle of 10.7°C, phase −199.8°.) We do not yet know whether the cycle in strain comes from thermoelastic deformation, or (quite possibly) incomplete correction of end-motion by the fiber anchors. Compared to any other near-surface strain record the annual cycle is small. Removing the secular rate and annual cycle gives the residual series of **Figure 2**. This shows that for much of the time, the strain fluctuations close to a fault zone are comparable to what we have observed at PFO, well outside any fault zone. The DHL record does show a few aseismic events, most lasting a few minutes, which we ascribe to local creep events on the nearby San Andreas fault: e.g. Events A, B, and H. (B, and other smaller events around that time, were also recorded on the other long-base strainmeter then running at DHL, so we are sure these were not instrumental artefacts.)

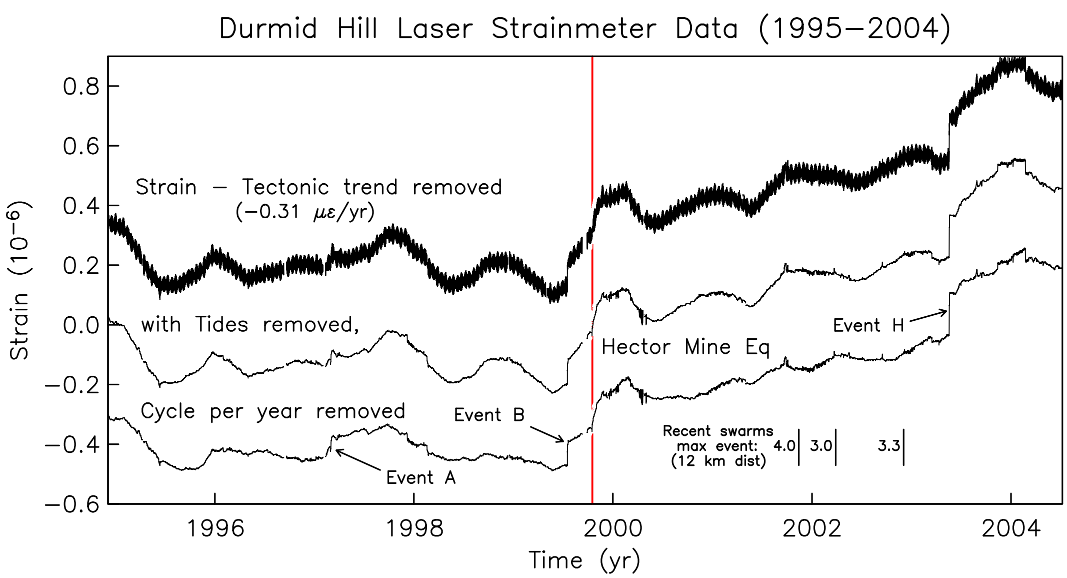

Figure 2

Activities at PFO (and to a lesser extent at DHL) fall into several groups, covered in the following sections: improvements in data access, general maintenance, instrument rebuilds (supported by NSF), and the activities of other groups at the site (supported also by other agencies).

1. Data Access

To get data from the PFO and DHL instruments to the wider community, we need (1) reliable data links from the site to our lab; (2) a system to collect the data and send it over these links; and (3) the procedures and personnel to make the data available to the community in an easily-usable form. The first of these has been available for some time, through the NSF-funded HP/WREN (*hpwren.ucsd.edu*) project, which provides wireless Internet connections to remote sites around San Diego; and RoadNet (*roadnet.ucsd.edu*), which integrates remote field sensors into a seamless data-transfer system. We have 45 Mb/s TCP/IP capability at the repeater on Toro Peak, overlooking both PFO and DHL, with a radio link to the PFO trailer providing 8 MBits/s to the local network. We have also made progress on the other two elements:

Telemetry and Data Recording. In 2002 we purchased an Internet-compatible data recorder for DHL: an onsite datalogger and strainmeter control system developed with funds from the DOE Yucca Mountain Project. This was installed at DHL and has been telemetering data since 2003:122. We also purchased (with SIO funds) a copy of this system for PFO; this had to be extended to handle 128 channels of data. The extension to 128 channels revealed some serious problems with the system not seen in our earlier 32-channel systems; through close cooperation with the system developer, we have been able to resolve these, and this datalogger is now under final test in our lab. We expect to install it at PFO in early 2005.

Data Handling. The datalogger provides raw data in real time through RoadNet, though our standard processing relies instead on a daily download. We have developed systems for producing combined raw data files and making them available on our Web site (*jacinto.ucsd.edu*); the main series of 5-minute sample data from DHL is updated fortnightly, and we will do the same with the PFO data once the new logger is installed. A bigger challenge is providing the data in a ''cleaned-up'' form that more users can deal with; a challenge, since some of the data editing can only be done by experienced personnel. We are working on this problem with support from the PBO, and will apply whatever developments we make to the PFO data. In the mean time, we have produced a release of our processing software, so that other users can work more easily with strainmeter data (Agnew 2004).

2. General Maintenance

Over the course of the year, we average 1–2 trips per month both to introduce new equipment and to fix problems with the instruments: typically the latter involves work on the facility and the laser strainmeters (lasers and vacuum systems). Much of the work reflects the age of some of the equipment at PFO: for example, all of our air conditioners are more than 15 years old (they have a nominal 7-year lifetime). We submitted an NSF proposal in June 2004 for a substantial purchase of standby and replacement equipment, along with upgrades to automate more of the operation. This has been funded at a bare-bones level to allow us to purchase some replacement equipment.

3. Instrument Rebuilds

In an earlier proposal to NSF, we had proposed to fully rebuild and anchor the EW longbase strainmeter, since independent high-stability strain measurements help considerably in interpreting low-level signals. We received reduced funding for this; because of building the SCIGN strainmeter in Glendale (GVS), and a strainmeter for the Yucca Mountain project (YMS) we did not start major reconstruction until 2002; this was completed in late 2003. **Figure 3** shows the data from this system. The benefits of deep-anchoring (W and E LOA monument-motion signals) are quite evident, leading to a high quality record of secular strain.

The first of five longbase strainmeters to be constructed by the Plate Boundary Observatory is a second, perpendicular component at DHL; this will be independent (aside from the power) of the USGS-supported system. At this point major construction is complete, and we anticipate operation beginning this spring.

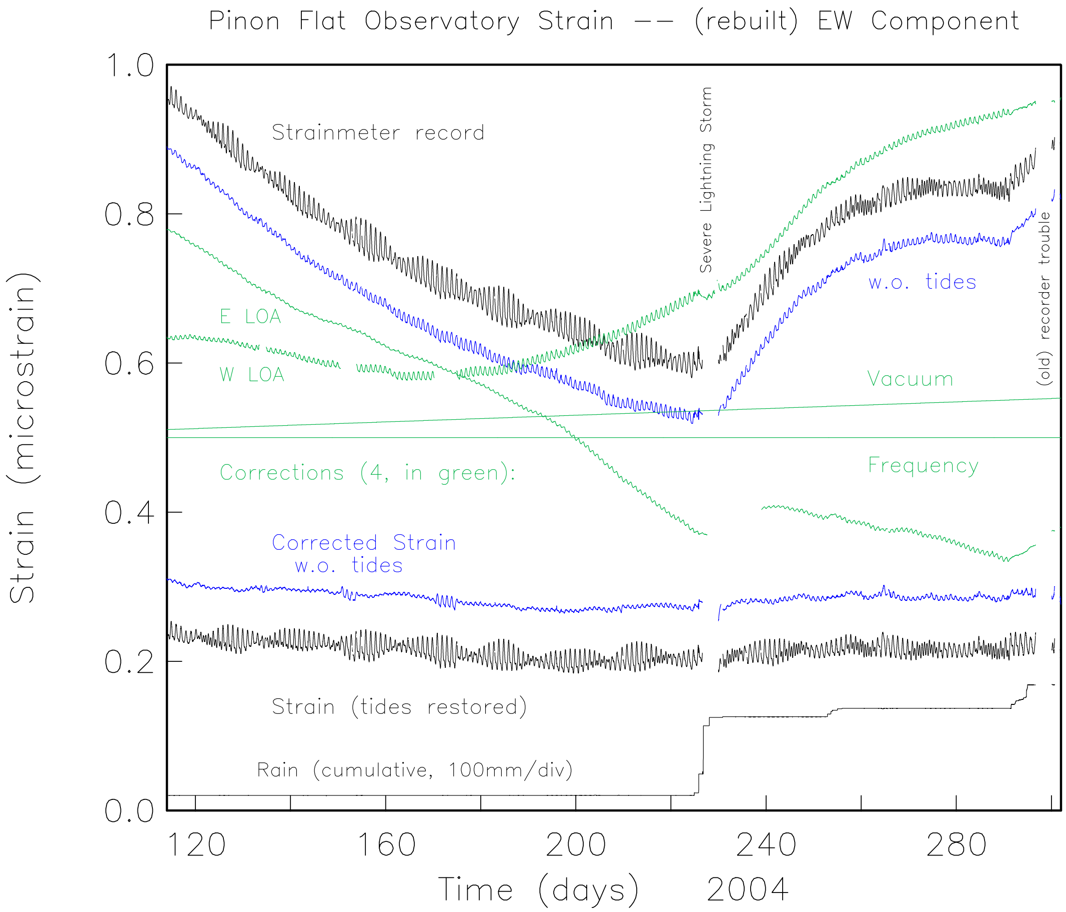

Figure 3

4. Other Activities

There have been a number of other activities at PFO during the last year; even for those not funded by the USGS, its support of the facility helps to keep it available for these many other efforts.

Seismic Test Facilities. With funds from NSF Ocean Sciences and other sources we are constructing an expanded set of subsurface vaults and boreholes that will house existing seismometers (such as the IDA/IRIS/EarthScope system) and provide a community facility at which interested researchers can test and calibrate seismic instruments. The vault includes two rooms with seismic piers (granite piers especially installed) and two rooms with facilities for mass testing of instruments. One of these will house a ring-laser gyro system with seismic sensitivity being installed by a group from the Technical University of Munich, Germany; when this is complete, it will make PFO the only place in the world with the ability to measure seismic displacements, rotations, and strains.

Water Wells. Since the early 1980's, we have monitored water-level changes in four wells at PFO (originally drilled for borehole strainmeters). All of these show tidal changes as the fractured-granite system responds to tidal changes in strain. A recent re-examination of these data, in collaboration with Prof. Emily Brodsky and Jean El-khoury of UCLA, shows changes in these tides (in some wells) coincident with earthquakes that have produced strong shaking at the site: both permanent changes (until the next shock) and transient changes that decay over the weeks following the earthquake. These presumably reflect changes in the local hydraulic regime, and can serve as a useful model for understanding how cracks in the crust can be affected by, and heal after, large dynamic strains—a topic of clear interest for understanding possible dynamic triggering of earthquakes.

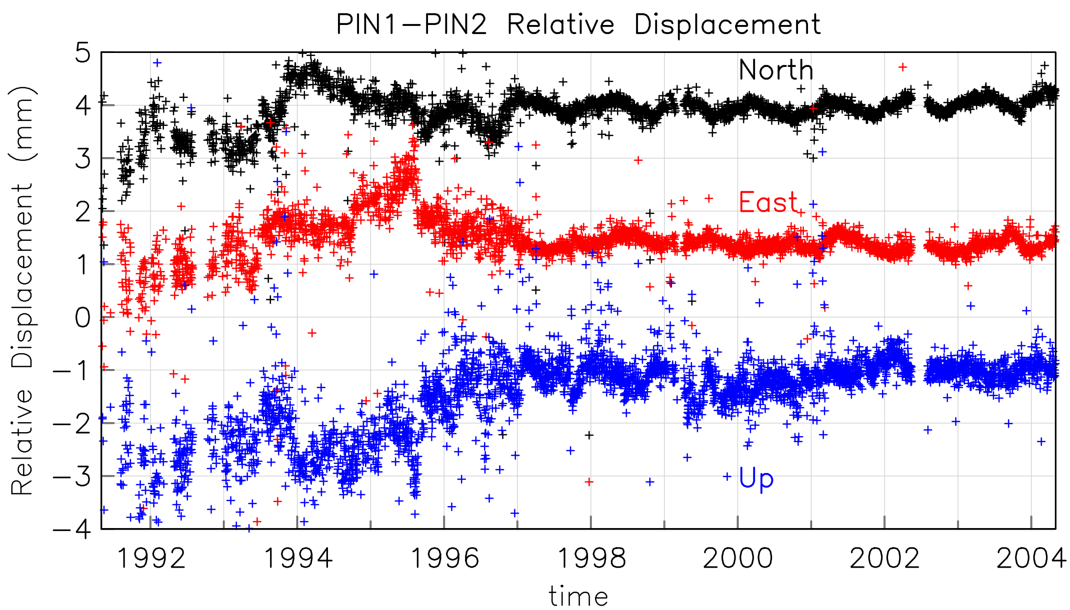

Figure 4

GPS Monumentation Another long-running PFO project is the operation of a pair of closely-spaced continuous GPS stations, PIN1 and PIN2, which are 50 m apart and both monumented using the drilled-braced monuments that have become a standard for SCIGN and the PBO (these two also happen to be the prototypes). In the last year we have undertaken a reanalysis of the data from these sites, and a review of the documentation of the (many) changes at them, to put together as complete a time history as possible (Wyatt and Agnew 2004). **Figure 4** shows the results. After correcting to a common point on the monuments, a number of offsets remain at the 1-2 mm level, probably because of errors in the antenna models for the early data (before 1997). When these are removed, we see remarkably little relative motion. We are working with Dr. Simon Williams (Bidston Observatory, Liverpool) on an analysis of this and other similar series. A preliminary result for the PFO data is that, after the offsets are removed, random-walk noise in the horizontals is below 0.2 mm/$\sqrt{\mathrm{yr}}$, a small value that confirms the quality of these installations (Agnew *et al.* 2005).

Non-Technical Summary

This grant supports the measurement of ground deformation around the San Jacinto and San Andreas faults using long-base laser strainmeters and long-base tiltmeters at two locations.

This enables us to see small changes in the motion of the ground over very long times (days and years), which may correlate with earthquakes. The most unusual motions recorded in recent years come from aftereffects of the Landers and Hector Mine earthquakes in 1992 and 1999, and from very small creep events on the San Andreas fault near one site.

Reports and Data Availability

We have several reports in preparation, as listed below. Our recent digital data (5-minute sampling, raw) from DHL are available at http://jacinto.ucsd.edu.

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